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The relationship between air pollutants and respiratory diseases for the western Turkey

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ABSTRACT

In this study, the effects of air pollutants on respiratory diseases were investigated for the western Turkey. Daily PM_{10} and SO_2 concentrations of four air quality monitoring stations were used, and hospital admission records of Canakkale province were provided by 18 Mart University Hospital for each age group for 2014–2018 period. The highest PM_{10} and SO_2 concentration values during the winter season were found in Can district. Among all air quality station records in Canakkale, PM_{10} and SO_2 values of Can Station exceeded the daily threshold limits set by WHO in 68% and 79% of the days, respectively.It was found that local and large-scale emission sources cause the highest PM_{10} concentrations in the cold season under low wind speed/calm weather conditions and during southerly winds that exceed 8 m/s. In terms of SO_2 concentrations, the highest values were also recorded in Can district and under low wind speed conditions or during calm days, only local emission sources increase the pollutant levels. This pollution is mainly caused by thermal power plants located in Can district. Analysis on relationship between air pollutants and respiratory diseases shows that, Asthma symptoms in children (0–14) were found to be positively correlated with both SO_2 concentrations (OR = 1.37; 95% Cl: 0.95–1.98) at lag 6 and PM_{10} concentrations (Odds ratio [OR] = 3.41; 95% confidence interval [CI]: 1.96–5.95). In addition, the OR value between PM_{10} (SO_2) and COPD was found positively significant ($p < 0.01$) at lag6 (lag5) in adults (elderly).

1. Introduction

Environmental pollution increases in various ways and threatens the environment and human health. Wildfires, traffic emissions, industrial activities and domestic heating can significantly increase the concentrations of the main pollutants (e.g. PM10, PM2.5, SO2, NO, NO2, CO, O3) in an urban area, and they can cause short-term health risks (Le et al., 2014; Degraeuwe et al., 2017; Fan et al., 2020; Hossain et al., 2020). WHO estimated that about 7 million people die annually from air pollution related diseases such as stroke, lung cancer, chronic obstructive pulmonary disease (COPD), pneumonia and chronic respiratory diseases (WHO, 2020). Epidemiological studies have shown that air pollution leads to many diseases, particularly damages the respiratory system (Atkinson et al., 2001; Analitis et al., 2006; Dominici et al., 2006; Chen et al., 2007; Kampa and Castanas, 2008; Stieb et al., 2009; Santus et al., 2012; Faustini et al., 2013; Tomášková et al., 2016; Geravandi et al., 2017; Jo et al., 2017; Khaefi et al., 2017; Saki et al., 2020; Effatpanah et al., 2020; Tahery et al., 2021). In terms of respiratory diseases, acute respiratory infection, asthma and COPD are the most significant ones that are affected by air pollutants (Medina-Ramón et al., 2006; Ko et al., 2007; Cirera et al., 2012; Canova et al., 2012; Meng et al., 2013; DeVries et al., 2016a; Li et al., 2016; Baltaci et al., 2020b). Particulate matter (PM) mostly affect the respiratory and cardiovascular symptoms (Pope et al., 2004; Tomczak et al., 2016; Deng et al., 2017; Jo et al., 2017; Cai et al., 2018; Chu et al., 2018; Xie et al., 2018), SO_2 (Pikhart et al., 2001; Wilson et al., 2005; Saygin et al., 2017). NO_x and O_3 also cause respiratory diseases (Chauhan et al., 2003; Barnett et al., 2005; Peacock et al., 2011; Hwang et al., 2016). Perez et al. (2015) found a significant relation between PM_{10} and NO_2 concentrations and daily emergency hospital admissions and mortality in Switzerland. Results showed that every 10 $\mu g/m^3$ increase in PM_{10} concentrations may result in a 0.7% increase in cardiovascular system problems and a 1.4% increase in respiratory disease problems. Santurtún et al. (2017) investigated the relationship between the air pollutant concentrations and

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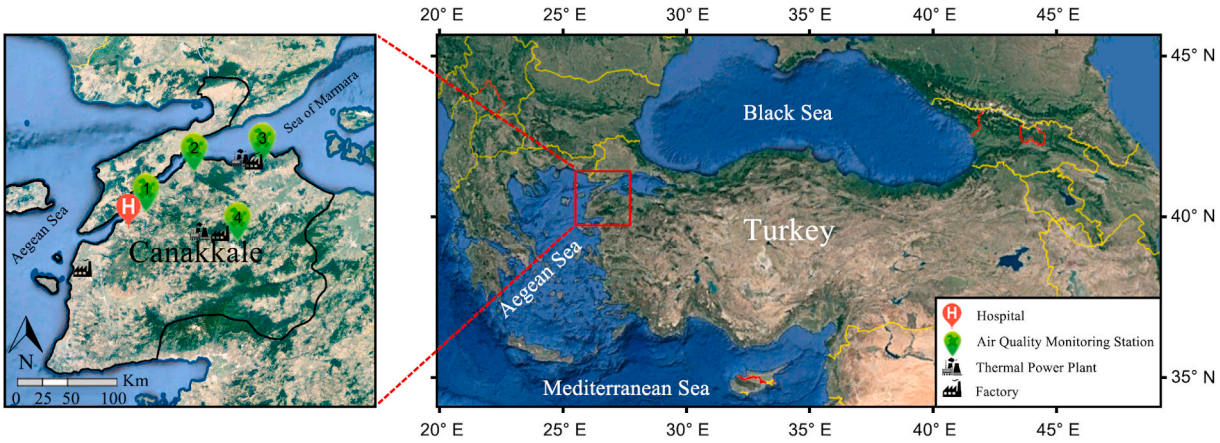


Fig. 1. The distribution of four air quality monitoring stations (black numbers with green circles) in Canakkale. Numbers 1, 2, 3, and 4 mark the locations of Canakkale, Lapseki, Biga, and Can air quality monitoring stations, respectively. The H term represents the Canakkale 18 Mart University Hospital located in the city center. The locations of the basic thermal power plant and factories are also shown in the Figure. The outset shows the Canakkale province in Turkey. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

COPD in Spain. They found that a high level of PM_{10} causes exacerbations in COPD patients.

In Turkey, air pollution has become an important issue because of the factors such as population growth and associated urbanization, rapid industrialization, continuous migration, and heavy utilization of fertilizers. Increasing pollutant concentrations result in adverse health effects. Although air pollution-health diseases relationship is very crucial for the country, very limited epidemiological studies have been carried up for Istanbul, Zonguldak, Kutahya, Isparta, Kirsehir and Ankara cities (Issever et al., 2005; Tecer et al., 2008; Ozcan and Cubukcu, 2015; Capraz et al., 2015, Kara and Kaynak, 2017). From the latest studies, Saygin et al. (2017) found strong correlation ($r = 0.59$, $p < 0.01$) between PM_{10} exposure and COPD and they found weak correlation ($r = 0.25$, $p > 0.05$) between PM_{10} and asthma in Isparta. Mercan et al. (2020) investigated the associations between the daily variations of PM_{10} and SO_2 and hospital admissions for asthma and COPD diseases in Kirsehir and they found significant correlations between PM_{10}, SO_2, asthma and COPD.

Factors such as presence of thermal power plants, industrial activities, immigration and maritime traffic density cause significant increase in pollutant concentration and associated hospital admissions in Canakkale district (western Turkey). Baltaci et al. (2020a) grouped high PM_{10} concentration sources by applying HYSPLIT 72-hr backward trajectory analysis and they clustered them with Ward's minimum clustering technique to emphasize the relationship between pollutants and hospital admissions. According to their results, high PM_{10} concentrations originating from Europe appear to cause especially pneumonia in elderly (>64) female at lag5 ($r = 0.55$, $p < 0.01$). Apart from that study, the effects of air pollutants on human health need to be examined in more detail for this region by considering a variety of pollutants and respiratory diseases. For this purpose, this study aims to investigate the relationship between PM_{10}, SO_2 concentration levels and hospital admissions (e.g. acute respiratory infection, asthma, COPD) in Canakkale province of Turkey for the 2014–2018 period.

2. Data and methodology

2.1. Hospital admissions and air quality data

In this study, the air quality data, which are managed by the Ministry of Environment and Urbanization, are obtained from the National Air Quality and Monitoring Network database (NAQMS, http://www.havaizleme.gov.tr/Services/AirQuality). At first, pollutant data of five Air Quality Monitoring Stations (e.g. Biga, Biga-ICDAS, Can, Lapseki and Merkez) in Canakkale were obtained from the related website. These monitoring stations are fully automated and provide hourly recordings. We removed incomplete recordings from the dataset and data validation and measurement techniques were applied as described in Sahin (2020). We used the pollutant data of four air quality stations in Canakkale (Fig. 1). Hourly mean PM_{10} and SO_2 values for Biga, Can and Merkez; $PM_{2.5}$ and SO_2 values for Lapseki were considered to be available for the analysis from January 2014 to December 2018 (Fig. 1). Additionally, to understand the impacts of local meteorological conditions on pollutant concentrations, hourly wind speed (m/s) and direction data, which were provided by the Turkish State Meteorological Service (TSMS), were used in the study by considering the meteorological stations closest to the air quality stations.

Daily hospital admission numbers for respiratory problems were obtained from the Canakkale 18 Mart University Hospital database for the same period as that of air quality data (1826 days). Data were collected according to the International Classification of Diseases-Tenth Revision (ICD-10), which is a diagnostic-based grouping developed by the World Health Organization (WHO). Daily respiratory hospital admission numbers (ICD-10: J00-06 for acute respiratory infection, ICD-10: J45 for asthma and ICD-10: J44 for COPD) are derived from the hospital database for each patient's age and gender. The relationship between PM_{10}, SO_2 with hospital admissions are investigated for the Canakkale Merkez air quality station (Number 1 in Fig. 1) as it is the closest station to the hospital.

2.2. Statistical analysis

Effects of pollutants on respiratory diseases were analyzed from lag0 to lag6 for each patient, similar to that of Baltaci et al. (2020b). It is known that lag0 means immediate exposure of pollutants, whereas, lag6 means six days after exposure. The reactions of patients to respiratory diseases caused by air pollution are different. Therefore, study was conducted for different age groups that are frequently used in the literature as: children (0–14 years), young adult (15–34 years), adult (35–64 years), elderly (>64 years). Risks of air pollutants on individuals are mainly expressed with relative risk (RR) or odds ratio (OR) (Tao et al., 2014; Lu et al., 2019; Zhang et al., 2020). Detailed explanations of these risk terms can be found in Andrade (2015). In this study, odds ratio (OR) and their 95% confidence intervals (CI) were calculated considering limit values of air pollutants (PM_{10} and SO_2) from WHO guideline and the effect duration of pollutants on each age group were determined. The WHO Air Quality Guideline has been created to protect human health from air pollutants. According to this guideline, daily

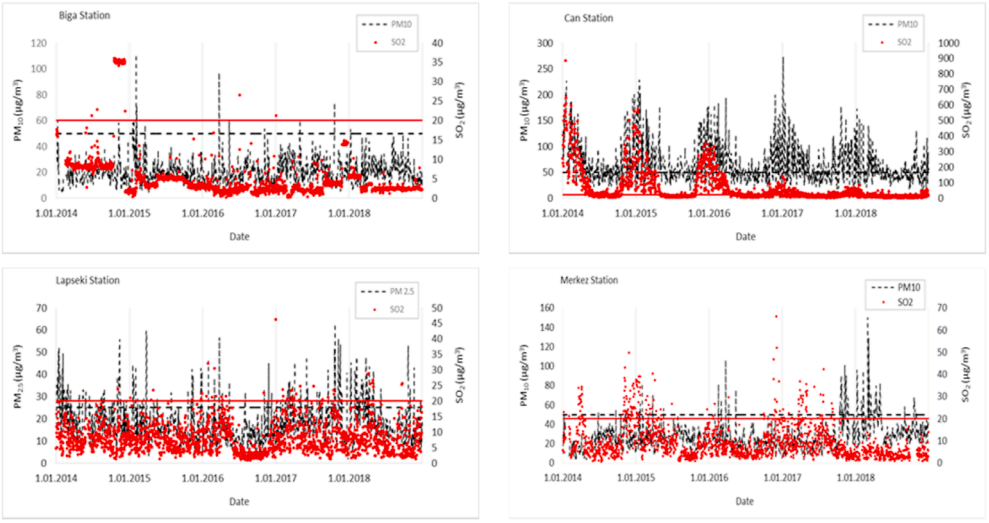


Fig. 2. Daily variations of PM_{10}, $PM_{2.5}$, SO_2 concentrations throughout the period 2014–2018 (The black dashed straight lines show the limit values of PM_{10}-$PM_{2.5}$, and the red solid line represents the limit values of SO_2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

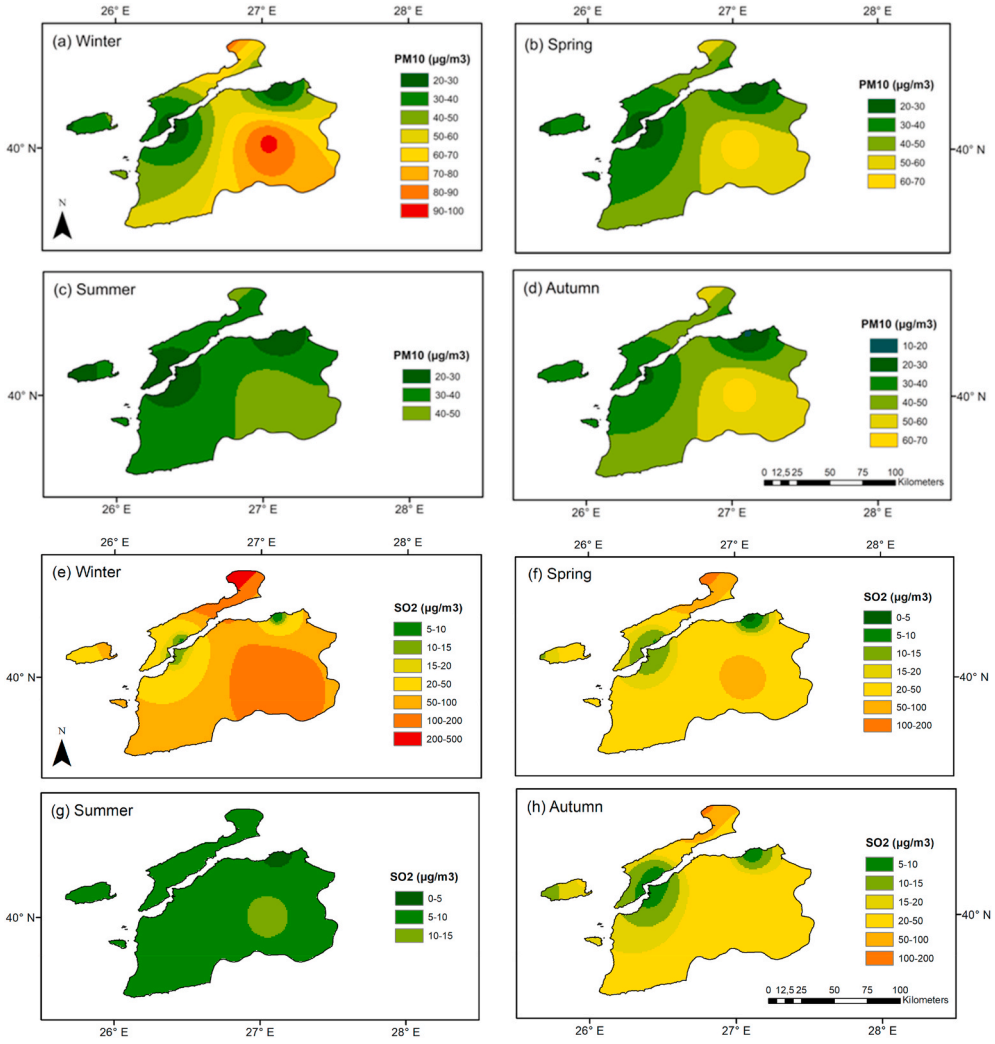


Fig. 3. Interpolation results of PM_{10} and SO_2 concentrations ($\mu g/m^3$) in 2014–2018.

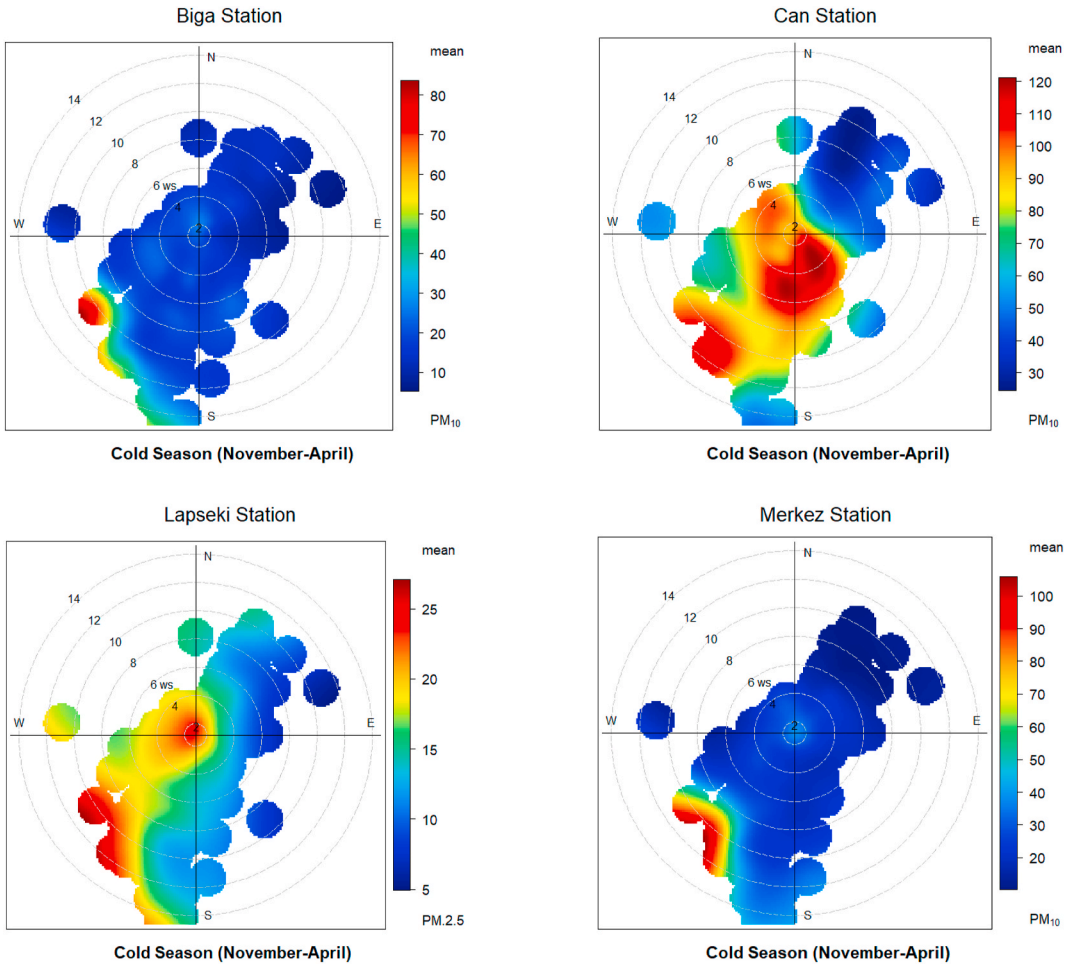


Fig. 4. Polar plots of PM_{10} and $PM_{2.5}$ mean concentrations for 2014–2018 during cold season in Canakkale.

threshold limits of $PM_{2.5}$, PM_{10} and SO_2 are 25, 50 and 20 μg/m^3, respectively.

In previous studies, OR values were calculated based on interquartile range (IQR) increments in each pollutant (Deng et al., 2016; Wang et al., 2020; Zhang et al., 2021) and each 10 μg/m^3 increase in exposure to air pollutants (Gu et al., 2020; Zhang et al., 2020). WHO declares that PM affects more people than any other pollutant and it is a common proxy indicator for air pollution. In this study, OR values were calculated based on WHO limit values for PM_{10} and SO_2. For this purpose, OR values and confidence intervals were calculated by using Statistical Package for the Social Sciences 27.0 (SPSS Inc., Chicago, IL, ABD). Later, polar plots were generated using R version 3.1.2 (R Core Team, 2015). The odds ratio (OR) of having respiratory diseases was calculated for all the assessed risk factors as follows: OR = (a/b)/(c/d) where a = exposed with respiratory diseases, c = not exposed with respiratory diseases, b = exposed without respiratory diseases, d = not exposed without respiratory diseases. Conditional logistic regression models were used to investigate exposure-response relationships between short-term air pollution exposures with different lag times and respiratory diseases by comparing data from the case and control days.

In order to find the locations and seasons with the highest pollutant concentrations, the seasonal variations over the region were extracted by using the inverse distance weighted (IDW) interpolation technique. This technique is known as one of the most commonly used methodology in air quality studies (Jumaah et al., 2019; Ma et al., 2019; Zeng et al., 2019; Gu et al., 2020). Seasonal concentration values of PM_{10} and SO_2 were extracted for the studied region by using IDW interpolation on a geographic information system (ArcGIS).

3. Results and discussion

3.1. Temporal variation of air pollutants

Daily variations of three air pollutants (PM_{10}, $PM_{2.5}$, SO_2) from four air quality stations and their trends were extracted from the long-term data for Canakkale, Turkey. When the measurement values in Canakkale were examined, it was found that PM_{10} values generally exceeds the WHO limit values (50 μg/m^3) at the Can station (Fig. 2). As mentioned by Mentese et al. (2020), Can had the worst air quality (industriliazed site) that negatively affect the respiratory symptoms of the patients. According to the $PM_{2.5}$ concentration recorded at Lapseki station, 17% of the measured daily $PM_{2.5}$ values exceed threshold values of WHO (25 μg/m^3). Previous studies stated that the human health problems are triggered when $PM_{2.5}$ exceeds the threshold (Polezer et al., 2018; Huang et al., 2019; Lee et al., 2019). Particularly, higher $PM_{2.5}$ and PM_{10} concentrations were observed at Merkez and Lapseki station during 2018 due to the long-range transport of dust particles from the Sahara (Baltaci et al., 2020b).

In addition to PM_{10}, SO_2 values also exceed the limit value (20 μg/m^3) at Can Station, especially during 2014 (75%). Particularly in winter season, Canakkale-Can Region was found as the most polluted province with annual concentration values significantly decreased due to the reduction in coal usage after 2016. Apart from the Can station, the second highest SO_2 values were observed at the Merkez station (Fig. 2). There are five operational coal-fired thermal power plants in Canakkale (Fig. 1). According to the European Environment Agency (EEA) report (2019), while electric consumption mostly releases sulphur oxide (SO_x)

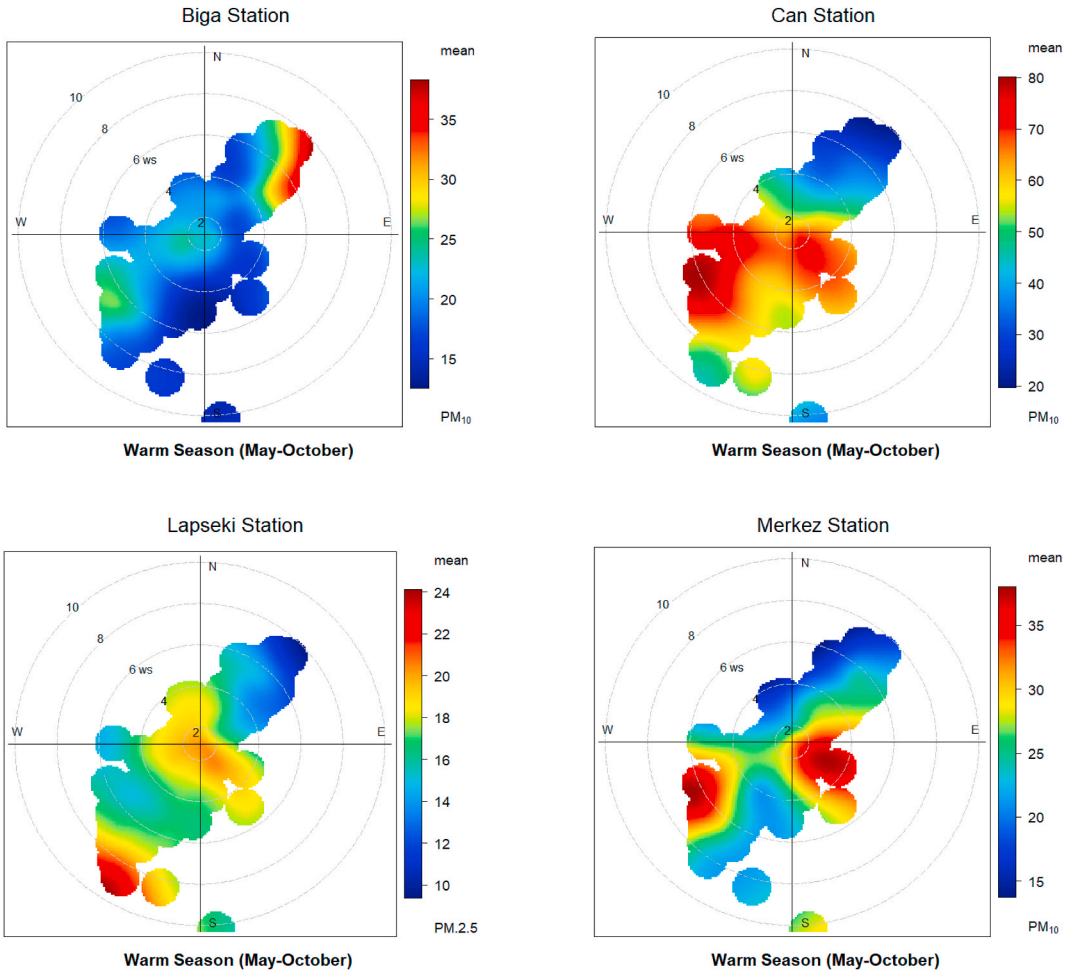


Fig. 5. Polar plots of PM_{10} and $PM_{2.5}$ mean concentrations for 2014–2018 during warm season in Canakkale.

and nitrogen oxide (NOx) to the atmosphere. Coal-fired thermal power plants especially increase PM and NO_2 emissions.

3.2. Seasonal variation of pollutants

As for the seasonal distribution of the pollutants, highest seasonal mean PM_{10} concentration levels were observed during winter (45 μg/m^3) and followed by spring (38 μg/m^3), autumn (37 μg/m^3), summer (31 μg/m^3) seasons respectively (Fig. 3). Winter having the highest concentrations is in agreement with the previous studies (Lv et al., 2019; Sindosi et al., 2019; Baltaci et al., 2020a). When compared to other stations, the highest mean value was found in the southern parts (e.g. Can station) as shown in Fig. 3a. It was noticed that 57% of the measured PM_{10} values exceeded the daily limit values determined by the WHO, European Union (EU) and Turkey. One of the main reasons causing high pollutant concentration values can be explained by topographical factors that prevent dispersion of pollutants to the surrounding environments. After winter, the second highest regional mean PM_{10} values are observed during spring (Fig. 3b), and previous studies indicated the role of Saharan dust transport to Canakkale province in this season (e.g. Baltaci et al., 2019). When Saharan dust particles are transferred by strong southwesterly winds, they do not meet any barrier (e.g. mountains) to reach western Turkey. If the local atmospheric conditions such as high temperature, no precipitation events, and low inversion level are present in the region, high amount of dust related to PM_{10} values could be seen. The lowest PM_{10} concentration levels were measured during summer and autumn seasons with almost 33, 59% of daily PM_{10} values exceed threshold levels respectively (Fig. 3c and d).

In addition to PM_{10}, the region is under the risk of high SO_2 concentrations during all seasons, except summer (Fig. 3g). In regional average, SO_2 levels were observed with 52 μg/m^3, 24 μg/m^3, and 20 μg/m^3 in winter, spring and autumn seasons, respectively (Fig. 3e, f, 3h). Similar to that of PM_{10} spatial distribution, the Can district shows higher SO_2 concentrations than the other stations. The factories in the region are generally located in the northern and southern parts of the region (3 and 4 numbers in Fig. 1). Biga seaside air quality station is settled in northern Canakkale, and prevailing northerly winds bring humid and clean air to the Biga region. Therefore, high SO_2 values in this basin are not observed in this region. On the other hand, the Can station shows high SO_2 concentrations in all seasons except summer due to large number of factories and thermal power plants, as well as pollution transport.

Industrial activities in the province affect the air quality of Canakkale in a negative way. There are three industrial zones in the city (Canakkale organized industrial zone (OIZ), Biga OIZ and Ezine OIZ). It is one of the cities where the threat of coal mining and coal-fired power plants has reached the most serious levels. For example, Can Lignite Plant in Can District, The Electricity Generation Company (EUAS) Can Thermal Power Plant, Kaleseramik Canakkale Kalebodur Ceramic Factories, Akcansa Cement and clinker production facility in Ezine District, iron and steel production facility belonging to ICDAS Steel, Energy, Shipbuilding and Transportation Industry Inc. in Biga District and ICDAS Bekirli Thermal Power Plant are important industrial facilities operating in the mining and energy sector. Due to the fact that Canakkale is a city where agricultural activities are intense, there are many industrial facilities that produce agriculture-based production (MEU, 2020). In

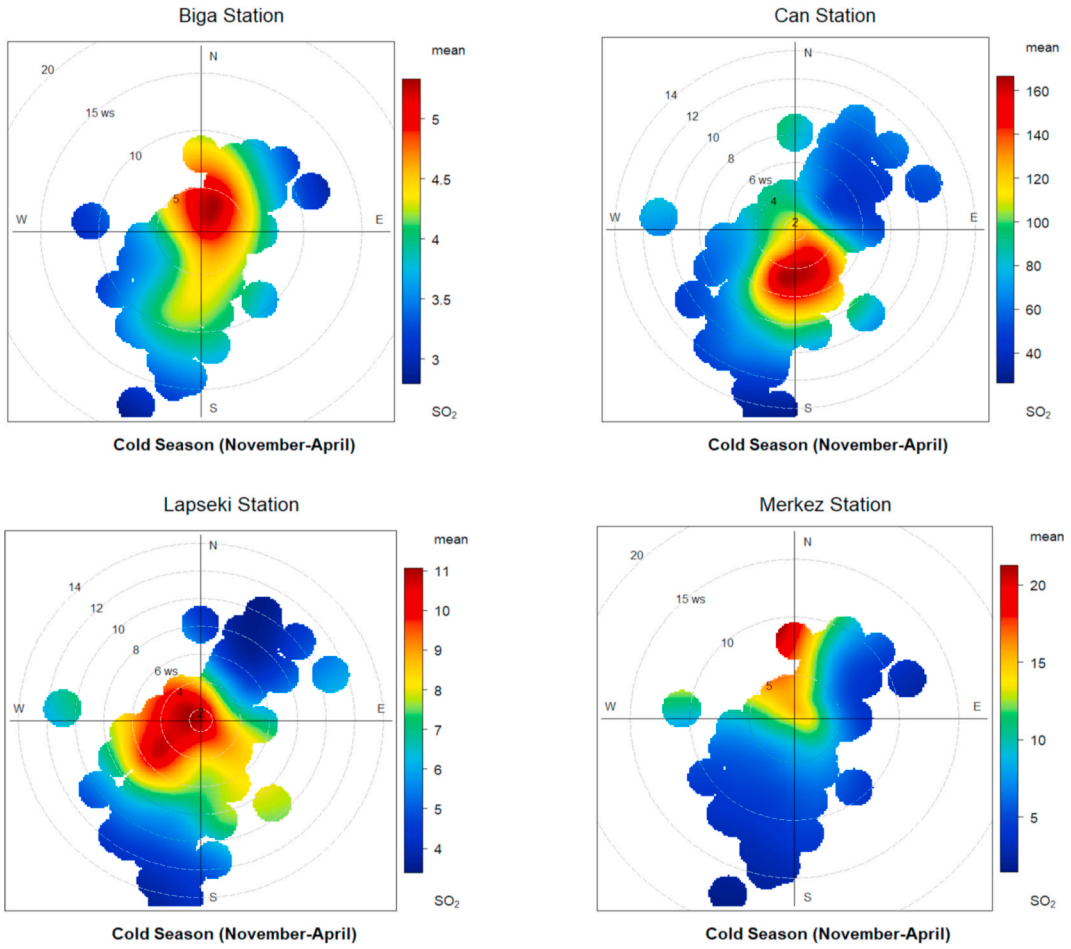


Fig. 6. Polar plots of SO_2 mean concentrations for 2014–2018 during cold season in Canakkale.

addition, low quality fuels used for heating purposes and high use of motor vehicles also reduce the air quality levels of the city.

Polar plot is a common method to find out the sources of atmospheric pollutants (Carslaw and Ropkins, 2012; Grange et al., 2016; Bigi et al., 2017; Khanum et al., 2017; Hama et al., 2019). Generalized additive model (GAM) is used to generate polar plot. Further details of the approach can be found in Carslaw and Beevers (2013) and Uria Tellaetxe and Carslaw (2014). Polar plots have been drawn to examine the relationship between pollutant concentrations and wind speed and direction.

In this study, sources of the emissions were investigated for cold (November to April) and warm (May to October) seasons of the city. The use of lignite, which causes poor air quality and high degree of pollution in Canakkale province, creates pollutants such as PM, SO_2, NO_X and O_3. As a result of using low quality fuels and applying improper combustion techniques in winter season, substantial amount of pollutants is released to the atmosphere and causes poor air quality and associated health diseases in Canakkale. According to the main results, multiple sources of $PM_{2.5}$ and PM_{10} were found during the cold season. Fig. 4 shows that locally sourced PM_{10} concentrations occur during low wind speeds and predominantly southerly directions in Can station. In Lapseki district, intensive ship crossings increase the concentrations of air pollutants.

On the other side, Can and Lapseki provinces get higher PM_{10} concentrations by southwesterly winds (above 8 m/s). This condition can be explained by the large-scale transport of Saharan dust particles to the region during spring months in cold season. As mentioned in previous studies, Saharan dust particles from Northern Africa passes over Mediterranean Sea and reach to the western of Turkey by strong southwesterly winds at the surface and mid-level of the atmosphere (Baltacı, 2017; Baltaci et al., 2019; Baltaci et al., 2020a). Apart from Can and Lapseki, Biga and Merkez stations are mainly influenced from long-range particle transport, instead of local emissions sources.

During the warm period, the intensity of vehicles and maritime traffic cause local air quality problems in Lapseki station (Fig. 5). The influence of large-scale PM_{10} transport can be shown in three stations by southwesterly directions, similar to that of cold period. However, long-range transport in Biga province shows different behavior. Northeasterly winds cause above-normal PM_{10} concentration levels due to maritime traffic. For Can station, local and large-scale emission sources influence the PM_{10} concentration levels during calm and strong southwesterly weather conditions. According to the polar plots results, Merkez station is affected by many sources in the region and is adversely affected by the emissions released to the atmosphere by the coal-fired thermal power plant in Can district.

Coal-fired thermal power plant and industries that use fossil fuels are the main contributors to SO_2 levels in the region. Additionally, high amount of SO_2 is transported from source region to long distances by atmospheric circulations. When SO_2 concentration were examined, three settlements (e.g. Biga, Can and Lapseki) were influenced by local emissions in different wind speed and directions (Fig. 6).

During warm season, the effects of long-range transport are more distinct in Can and Lapseki stations, when compared to the cold period. In addition to this, Lapseki and Merkez stations also influenced by local emission sources (Fig. 7).

In general, cold season pollutant concentrations are higher than warm season in Canakkale. Industrial activity, vehicle exhaust, maritime traffic, residential heating, and long-range particle transport play key role in having high amount of pollutant concentrations in this season. In

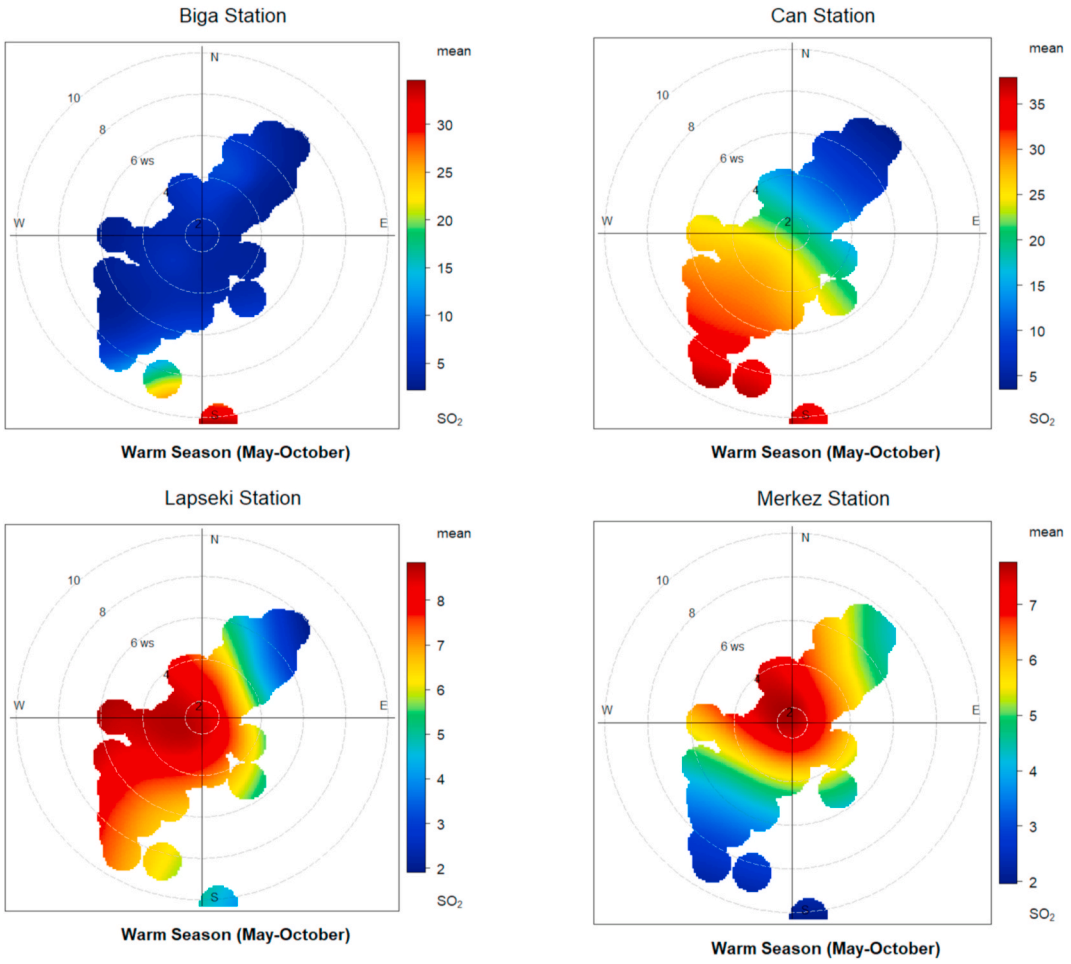


Fig. 7. Polar plots of SO_2 mean concentrations for 2014–2018 during warm season in Canakkale.

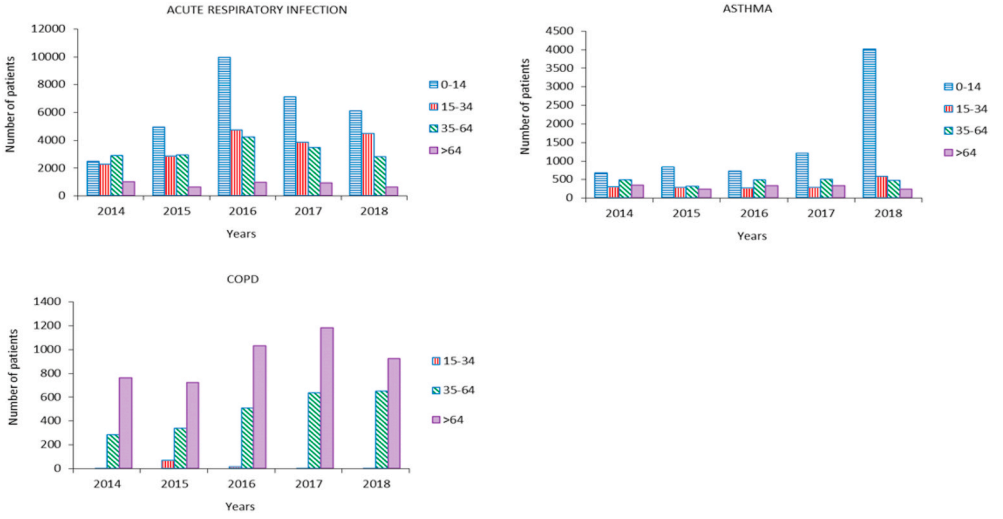


Fig. 8. Yearly number of patients for asthma, COPD and acute respiratory infections by age.

addition to cold and warm season concentrations, seasonal concentration polar plots of air pollutants were given in Fig. S1 (Fig. S1, see supplementary S1).

3.3. Patient characteristics

Several epidemiological studies have reported significant associations between air pollutant and hospital admissions for respiratory diseases. Some of the most common are acute respiratory infections, asthma, and COPD (Darrow et al., 2014; Zheng et al., 2017; Nhung et al.,

Table 1
Relationship between PM_{10} and hospital admissions for asthma at lag0-lag6.

Pollutant (μg/m^3)	Lag	Asthma			
		0-14 (yrs)	15-34 (yrs)	35-64 (yrs)	>64 (yrs)
PM_{10}	0	2.113 (1.308–3.411) **	1.995 (1.335–2.983) **	1.133 (0.765–1.679) **	1.090 (0.738–1.609) **
	1	1.606 (1.027–2.511) **	1.916 (1.284–2.859) **	1.120 (0.756–1.659) **	1.094 (0.741–1.615) **
	2	1.996 (1.245–3.199) **	1.762 (1.185–2.620) **	1.358 (0.910–2.026) **	1.227 (0.832–1.809) **
	3	2.391 (1.456–3.927) **	1.606 (1.083–2.382) **	1.163 (0.784–1.725) **	1.044 (0.706–1.542) **
	4	2.919 (1.722–4.948) **	1.754 (1.179–2.607) **	1.176 (0.793–1.745) **	1.073 (0.727–1.585) **
	5	2.212 (1.359–3.601) **	1.619 (1.092–2.400) **	1.084 (0.732–1.604) **	0.890 (0.600–1.319) **
	6	3.415 (1.961–5.948) **	1.920 (1.287–2.864) **	1.170 (0.789–1.735) **	1.071 (0.725–1.581) **

**p < 0.01.

Table 2
Relationship between PM_{10} and hospital admissions for COPD at lag0-lag6.

Pollutant (μg/m^3)	Lag	COPD		
		15-34 (yrs)	35-64 (yrs)	>64 (yrs)
PM_{10}	0	1.204 (0.365–3.975)	1.388 (0.928–2.074) **	1.396 (0.863–2.258) **
	1	0.773 (0.184–3.250)	1.285 (0.863–1.913) **	1.076 (0.687–1.687) **
	2	2.233 (0.854–5.841) **	1.652 (1.095–2.492) **	1.200 (0.757–1.901) **
	3	2.165 (0.829–5.651) **	1.374 (0.919–2.055) **	1.137 (0.722–1.791) **
	4	2.703 (1.107–6.597) **	1.514 (1.008–2.273) **	1.138 (0.722–1.793) **
	5	1.236 (0.374–4.083)	2.078 (1.355–3.188) **	1.598 (0.971–2.629) **
	6	1.272 (0.384–4.209)	2.411 (1.551–3.747) **	1.703 (1.025–2.828) **

**p < 0.01.

2018). Acute respiratory infections (ARI) are the main cause of mortality and morbidity in children (Zheng et al., 2017). When the distribution of respiratory diseases by age in Canakkale province is examined for 2014–2018 period, the highest acute respiratory disease case was found in children aged 0–14, followed by 15–34, 35–64 and > 64 age groups respectively.

Asthma is the most common respiratory disease among children worldwide (WHO, 2020). Generally, it starts in childhood, although it also could develop in adults. It affects people of all ages. In 2018, high daily numbers of intensive dust loadings were transported from the Sahara to whole Turkey (Baltaci, 2021). This atmospheric condition can be the main reason of high asthma incidence (Fig. 8). It is known that

Table 5
Relationship between SO_2 and hospital admissions for COPD at lag0-lag6.

Pollutant (μg/m^3)	Lag	COPD		
		15-34 (yrs)	35-64 (yrs)	>64 (yrs)
SO_2	0	0.509 (0.122–2.128)	0.989 (0.707–1.384) **	1.155 (0.778–1.713) **
	1	1.119 (0.393–3.186)	1.053 (0.752–1.475) **	1.095 (0.740–1.619) **
	2	0.522 (0.125–2.184)	1.141 (0.813–1.601) **	1.069 (0.723–1.582) **
	3	1.491 (0.574–3.869)	0.977 (0.698–1.367) **	1.249 (0.835–1.867) **
	4	1.149 (0.403–3.278)	1.018 (0.727–1.425) **	1.371 (0.909–2.068) **
	5	1.799 (0.743–4.355)	1.566 (1.103–2.222) **	2.047 (1.295–3.236) **
	6	2.177 (0.946–5.008) **	1.198 (0.852–1.684) **	1.554 (1.015–2.378) **

**p < 0.01.

Table 3
Relationship between PM_{10} and hospital admissions for acute respiratory infections at lag0-lag6.

Pollutant (μg/m^3)	Lag	Acute Respiratory Infections			
		0-14 (yrs)	15-34 (yrs)	35-64 (yrs)	>64 (yrs)
PM_{10}	0	1.720 (0.414–7.193)	0.987 (0.981–0.992)	0.460 (0.158–1.339) **	1.291 (0.798–2.090) **
	1	0.969 (0.961–0.978) **	0.987 (0.982–0.993)	0.351 (0.132–0.933) **	1.464 (0.890–2.411) **
	2	1.069 (0.327–3.495)	1.326 (0.176–10.002)	0.478 (0.165–1.388) **	1.446 (0.878–2.380) **
	3	3.417 (0.467–24.996)	0.987 (0.982–0.993)	0.667 (0.200–2.226)	1.136 (0.712–1.813) **
	4	0.969 (0.960–0.977)	0.987 (0.982–0.993)	0.691 (0.207–2.301)	0.996 (0.632–1.571) **
	5	1.622 (0.389–6.774)	1.329 (0.176–10.022)	0.598 (0.178–2.007)	1.244 (0.768–2.014) **
	6	1.072 (0.328–3.504)	1.259 (0.167–9.521)	0.598 (0.178–2.008)	1.411 (0.857–2.323) **

**p < 0.01.

Table 4
Relationship between SO_2 and hospital admissions for asthma at lag0-lag6.

Pollutant (μg/m^3)	Lag	Asthma			
		0-14 (yrs)	15-34 (yrs)	35-64 (yrs)	>64 (yrs)
SO_2	0	1.035 (0.727–1.472) **	0.891 (0.637–1.245) **	0.788 (0.565–1.100) **	1.058 (0.757–1.478) **
	1	1.322 (0.914–1.911) **	0.766 (0.546–1.074) **	0.996 (0.712–1.393) **	1.264 (0.905–1.764) **
	2	1.175 (0.818–1.687) **	0.782 (0.558–1.095) **	1.197 (0.852–1.682) **	1.170 (0.838–1.633) **
	3	0.959 (0.676–1.361) **	0.833 (0.595–1.165) **	0.964 (0.690–1.348) **	1.021 (0.730–1.427) **
	4	1.061 (0.744–1.512) **	1.020 (0.730–1.424) **	0.923 (0.661–1.289) **	1.233 (0.883–1.721) **
	5	1.354 (0.937–1.958) **	1.046 (0.749–1.460) **	1.125 (0.803–1.577) **	1.305 (0.935–1.822) **
	6	1.371 (0.949–1.982) **	0.973 (0.696–1.358) **	1.281 (0.911–1.803) **	1.189 (0.852–1.660) **

**p < 0.01.

Table 6
Relationship between SO_2 and hospital admissions for acute respiratory infections at lag0-lag6.

Pollutant (μg/m^3)	Lag	Acute Respiratory Infections			
		0-14 (yrs)	15-34 (yrs)	35-64 (yrs)	>64 (yrs)
SO_2	0	0.584 (0.271–1.259) **	0.945 (0.218–4.096)	2.616 (0.352–19.410)	1.140 (0.758–1.714**
	1	0.461 (0.220–0.964) **	0.526 (0.152–1.827)	2.515 (0.338–18.691)	1.158 (0.770–1.740) **
	2	0.510 (0.235–1.107) **	0.493 (0.141–1.724)	2.517 (0.339–18.703)	0.822 (0.562–1.202) **
	3	0.393 (0.193–0.800) **	0.343 (0.111–1.056)	2.518 (0.339–18.716)	0.923 (0.626–1.362) **
	4	0.741 (0.311–1.766) **	1.908 (0.254–14.349)	0.829 (0.247–2.778)	1.016 (0.684–1.509) **
	5	0.573 (0.253–1.301) **	0.594 (0.173–2.041)	1.303 (0.306–5.546)	1.085 (0.725–1.624) **
	6	0.617 (0.273–1.395) **	0.561 (0.163–1.938) **	2.626 (0.354–19.488)	1.003 (0.675–1.490) **

**$p < 0.01$.

COPD is a major health problem in adults over 40 (WHO, 2020). Therefore, 0–14 age group for COPD was removed from the study. The highest COPD cases were observed in aged >64, followed by 35–64, respectively.

3.4. Relationship between pollutants and number of patients

OR was used to analyze the relationship between PM_{10}, SO_2 and respiratory diseases. For this reason, 95% confidence intervals and 99% statistical significance levels of this relationship were calculated for each age group and lag (See Tables1–3).

The highest OR values between PM_{10} and asthma were found at lag6 (OR = 3.41; 95% Cl, 1.96–5.95) in the children and followed by the 15–34 age group (Table 1). Similar findings were also evident in a previous study as Nastos et al. (2010) reported a significant relationship between PM_{10} and hospital admissions for asthma in Greece (OR = 1.46; 95% Cl, 0.950–2.241). In their study, Lu et al. (2019) found a significant relationship between air pollutants and hospital admissions for asthma in China for PM_{10} (OR = 1.006; 95% Cl, 1.002–1.009) and for SO_2 (OR = 1.017; 95% Cl, 1.008–1.026) with the 35–64 years age group. PM_{10} had significant impacts on people aged ≥65 years (OR = 1.013; 95% Cl, 1.004–1.022.

When the relationship between COPD patients and PM_{10} values were examined, it was observed that the age groups 35–64 and > 64 are more influenced by PM_{10} than the 15–34. Similar PM_{10}-COPD associations were also found in the previous study published by Baltaci et al., (2020b). It was found that the age group 15–34 was most affected at lag4 (OR = 2.70; 95% Cl, 1.11–6.60), while the age groups 35–64 (OR = 2.41; 95% Cl, 1.55–3.75) and >64 (OR = 1.70; 95% Cl, 1.03–2.83) were most influenced at lag6 (Table 2). Previous studies such as Schikowski et al. (2005) reported a similar significant relationship between PM_{10} and COPD (OR = 1.33; 95% CI 1.03–1.72) in Germany. DeVries et al. (2016b) found that short-term exposures to SO_2 were associated with an increase in COPD exacerbation risk (OR = 2.45, 95% CI: 1.75–3.45) in Massachusetts.

Table 3 shows that the age group >64 is most affected by acute respiratory infections at lag1 (OR = 1.50; 95% Cl, 0.89–2.41). Nhung et al. (2019) showed that PM_{10} (OR = 1.004; 95% Cl, 0.980–1.028) and SO_2 (OR = 1.069; 95% Cl, 1.011–1.130) concentrations were associated with acute respiratory infections for the age group 0–5.

The highest OR value was observed between asthma and SO_2 values for children at lag 6 (OR = 1.37; 95% Cl, 0.95–1.98) and at lag 5 (OR = 1.31; 95% Cl, 0.96–1.82) in the elderly, respectively (Table 4).

Table 5 shows that association between SO_2 and COPD. The most affected age group is > 64 and it is followed by adults. Stronger associations were observed at lag 5 among elderly (OR = 2.05; 95% Cl, 1.30–3.24) and adults (OR = 1.57; 95% Cl, 1.10–2.22). However, the highest OR value was found in the age group 15–34 at lag6 (OR = 2.18; 95% Cl, 0.95–5.01).

When the relationship between acute respiratory infection patients and SO_2 concentrations were analyzed, it was found that the age groups 0–14 and > 64 are more affected by SO_2 than the other age groups. It was observed that the age group 0–14 is most affected at lag4, while the age groups >64 are most influenced at lag1 (Table 6). The highest OR value was observed in the elderly (OR = 1.16; 95% Cl, 0.77–1.74). Previous studies such as Lu et al. (2019) and Zhao et al. (2019) have reported similar results.

4. Conclusion

In this study, the effects of PM_{10} and SO_2 concentration on respiratory diseases were analyzed for Canakkale from 2014 to 2018. Air pollutants were recorded above the WHO limit values in Canakkale, especially in Can district of the city due to the geographical closeness of thermal power plants. In terms of PM_{10}, 69%, 66% and 59% of all days exceed WHO threshold limits in winter, spring and autumn, respectively. In addition to PM_{10}, 82%, 65% and 46% of daily SO_2 values exceed threshold level. The results based on the relationship between air pollutants and respiratory diseases indicated that PM_{10} (OR = 3.41; 95% CI: 1.96–5.95) and SO_2 (OR = 1.37; 95% Cl: 0.95–1.98) were positively associated with asthma disease at lag6 in children. In terms of COPD, highest OR value between PM_{10} and COPD were observed in adult (OR = 2.41; 95% Cl: 1.55–3.75) at lag6, while SO_2 values were significantly associated with COPD in the elderly (OR = 2.05; 95% Cl: 1.30–3.24) at lag5. Abundance of coal-fired thermal plants and fossil fuel industry in Can increase the frequency of health diseases, and hence, renewable energy sources should be used more frequently in the future.

Data availability

The datasets analyzed during the current study are available on corresponding author request.

Limitations

The limitation of the study is that some of the measurement data from air quality monitoring stations in Çanakkale had to be excluded due to being incomplete. For example, PM_{10} and SO_2 concentrations were not measured in Lapseki, and $PM_{2.5}$ concentrations were not recorded in Can, Lapseki and Merkez.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apr.2022.101322.

References

Analitis, A., Katsouyanni, K., Dimakopoulou, K., Samoli, E., Nikoloulopoulos, A.K., Petasakis, Y., Touloumi, G., Schwartz, J., Anderson, H.R., Cambra, K., Forastiere, F., Zmirou, D., Vonk, J.M., Clancy, L., Kriz, B., Bobvos, J., Pekkanen, J., 2006. Short-term effects of ambient particles on cardiovascular and respiratory mortality. Epidemiology 17, 230–233.

Andrade, C., 2015. Understanding relative risk, odds ratio, and related terms: as simple as it can get. J. Clin. Psychiatr. 76 (7), e857–e861.

Atkinson, R.W., RossAnderson, H., Sunyer, J., Ayres, J., Baccini, M., Vonk, J.M., Boumghar, A., Forastiere, F., Forsberg, B., Touloumi, G., Schwartz, J., Katsouyanni, K., 2001. Acute effects of particulate air pollution on respiratory admissions. Am. J. Respir. Crit. Care Med. 164 (10), 1860–1866.

Baltacı, H., 2017. Spatial and temporal variation of the extreme Saharan dust event over Turkey in March 2016. Atmosphere 8, 41.

Baltaci, H., Akkoyunlu, B.O.A., Arslan, H., Yetemen, O., Ozdemir, E.T., 2019. The influence of meteorological conditions and atmospheric circulation types on PM_{10} levels in western Turkey. Environ. Monit. Assess. 191, 466.

Baltaci, H., Alemdar, C.S.O., Akkoyunlu, B.O., 2020a. Background Atmospheric Conditions of High PM_{10} Concentrations in Istanbul, Turkey. Atmospheric Pollution Research.

Baltaci, H., Arslan, H., Akkoyunlu, B.O., 2020b. High PM_{10} source regions and their influence on respiratory diseases in Canakkale, Turkey. Int. J. Environ. Sci. Technol. htpps://doi.org/10.1007/s13762-020-02914-7.

Baltaci, H., 2021. Meteorological characteristics of dust storm events in Turkey. Aeolian Res. htpps://doi.org/10.1016/j.aeolia.2021.100673.

Barnett, A.G., Williams, G.M., Schwartz, J., Neller, A.H., Best, T.L., Petroeschevsky, A.L., Simpson, R.W., 2005. Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand. Am. J. Respir. Crit. Care Med. 171, 1272–1278.

Bigi, A., Bianchi, F., De Gennaro, G., Di Gilio, A., Fermo, P., Ghermandi, G., Prevot, A.S. H., Urbani, N., Valli, G., Vecchi, R., Piazzalunga, A., 2017. Hourly composition of gas and particle phase pollutants at a central urban background site in Milan, Italy. Atmos. Res. 186, 83–94.

Cai, J., Yu, S., Pei, Y., Peng, C., Liao, Y., Liu, N., Ji, J., Cheng, J., 2018. Association between airborne fine particulate matter and residents' cardiovascular diseases, ischemic heart disease and cerebral vascular disease mortality in areas with lighter air pollution in China. Int. J. Environ. Res. Publ. Health 15, 1918.

Canova, C., Dunster, C., Kelly, F.J., Minelli, C., Shah, P.L., Caneja, C., Tumilty, M.K., Burneya, P., 2012. PM_{10}-induced hospital admissions for asthma and chronic obstructive pulmonary disease: the modifying effect of individual characteristics. Epidemiology 23, 607–615.

Capraz, O., Efe, B., Deniz, A., 2015. Study on the association between air pollution and mortality in Istanbul, 2007-2012. Atmos. Pollut. Res. 1–8.

Carslaw, D.C., Beevers, S.D., 2013. Characterising and understanding emission sources using bivariate polar plots and k-means clustering. Environ. Model. Software 40, 325–329.

Carslaw, D.C., Ropkins, K, 2012. Openair, An R package for air quality data analysis. Environ. Model. Software 27-28, 52–61.

Chauhan, A.J., Inskip, H.M., Linaker, C.H., Smith, S., Schreiber, J., Johnston, S.L., Holgate, S.T., 2003. Personal exposure to nitrogen dioxide (NO_2) and the severity of virusinduced asthma in children. Lancet 361, 1939–1944.

Chen, T.M., Gokhale, J., Shofer, S., Kuschner, W.G., 2007. Outdoor air pollution: nitrogen dioxide, sulfur dioxide and carbon monoxide health effects. Am. J. Med. Sci. 333, 249–256.

Chu, Y.H., Kao, S.W., Tantoh, D.M., Ko, P.C., Lan, S.J., Liaw, Y.P., 2018. Association between fine particulate matter and oral cancer among Taiwanese men. J. Invest. Med. 67, 34–38.

Cirera, L., Garcia-Marcos, L., Gimenez, J., Moreno-Graud, S., Tobíase, A., Pérez-Fernández, V., Elvira-Rendelese, B., Guilléna, J.J., Navarroa, C., 2012. Daily effects of air pollutants and pollen types on asthma and COPD hospital emergency visits in the industrial and Mediterranean Spanish city of Cartagena. Allergol. Immunopathol. 40, 231–237.

Darrow, L.A., Klein, M., Flanders, W.D., Mulholland, J.A., Tolbert, P.E., Strickland, M.J., 2014. Air pollution and acute respiratory infections among children 0–4 Years of age: an 18-year time-series study. Am. J. Epidemiol. 180 (10), 968–977.

Degraeuwe, B., Thunis, P., Clappier, A., Weiss, M., Lefebvre, W., Janssen, S., Vranckx, S., 2017. Impact of passenger car NO_X emissions on urban NO_2 pollution – scenario analysis for 8 European cities. Atmos. Environ. 171, 330–337.

Deng, Q., Lu, C., Li, Y., Sundell, J., Norbäck, D., 2016. Exposure to outdoor air pollution during trimesters of pregnancy and childhood asthma, allergic rhinitis, and eczema. Environ. Res. 150, 119–127.

Deng, H., Eckel, S.P., Liu, L., Lurmann, F.W., Cockburn, M.G., Gilliland, F.D., 2017. Particulate matter air pollution and liver cancer survival. Int. J. Cancer 141, 744–749.

DeVries, R., Kriebel, D., Sama, S., 2016a. Outdoor Air pollution and COPD-related emergency department visits, hospital admissions and mortality: a meta-analysis. COPD 14 (1), 113–121.

DeVries, R., Kriebel, D., Sama, S., 2016b. Low level air pollution and exacerbation of existing COPD: a case crossover analysis. Environ. Health 15 (1). https://doi:10.1186/s12940-016-0179-z.

Dominici, F., Peng, R.D., Bell, M.L., Pham, L., McDermott, A., Zeger, S.L., Samet, J.M., 2006. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 295, 1127–1134.

Effatpanah, M., Effatpanah, H., Jalali, S., Parseh, I., Goudarzi, G., Barzegar, G., Geravandi, S., Darabi, F., Ghasemian, N., Mohammadi, M.J., 2020. Hospital admission of exposure to air pollution in Ahvaz megacity during 2010–2013. Clin. Epidemiol. Global Health 8 (2), 550–556.

European Environment Agency, 2019. European union emission inventory report 1990-2017 under the UNECE convention on long-range transboundary air pollution (LRTAP). EEA technical report. No 9/2019, Copenhagen.

Fan, Y., Ding, X., Hang, J., Ge, J., 2020. Characteristics of urban air pollution in different regions of China between 2015 and 2019. Build. Environ. 180, 107048.

Faustini, A., Stafoggia, M., Paola Colais, P., Berti, G., Bisanti, L., Cadum, E., Cernigliaro, A., Mallone, S., Scarnato, C., Forastiere, F., 2013. Air pollution and multiple acute respiratory outcomes. European Respiratory J. 42, 304–313.

Geravandi, S., Sicard, P., Khaniabadi, Y.O., De Marco, A., Ghomeishi, A., Goudarzi, G., Mahboubi, M., Yari, A.R., Dobaradaran, S., Hassani, G., Mohammadi, M.J., 2017. A comparative study of hospital admissions for respiratory diseases during normal and dusty days in Iran. Environ. Sci. Pollut. Res. 24 (22), 18152–18159.

Grange, S.K., Lewis, A.C., Carslaw, D.C., 2016. Source apportionment advances using polar plots of bivariate correlation and regression statistics. Atmos. Environ. 145, 128–134.

Gu, K., Zhou, Y., Sun, H., Dong, F., Zhao, L., 2020. Spatial distribution and determinants of $PM_{2.5}$ in China's cities: fresh evidence from IDW and GWR. Environ. Monit. Assess. 193, 15. https://doi.org/10.1007/s10661-020-08749-6.

Hama, S.M.L., Kumar, P., Harrison, R., Bloss, W.J., Khare, M., Mishra, S., Namdeo, A., Sokhi, R., Goodman, P., Sharma, C., 2019. Four-year Assessment of Ambient Particulate Matter and Trace Gases in the Delhi-NCR Region of India. Sustainable Cities and Society, p. 102003.

Hossain, M.S., Frey, H.C., Louie, P.K.K., Lau, A.H., 2020. Combined effects of increased O_3 and reduced NO_2 concentrations on short-term air pollution health risks in Hong Kong. Environ. Pollut. 270, 116280.

Huang, R., Hu, Y., Russell, A.G., Mulholland, J.A., Odman, M.T., 2019. The impacts of prescribed fire on $PM_{2.5}$ air quality and human health: application to asthma-related emergency room visits in Georgia, USA. Int. J. Environ. Res. Publ. Health 16 (13), 2312.

Hwang, S.H., Choi, H.Y., Paik, H.J., Wee, W.R., Kim, M.K., Kim, D.H., 2016. Potential importance of ozone in the association between outdoor air pollution and dry eye disease in South Korea. JAMA Ophthalmology 134, 503–510.

Issever, H., Disci, R., Hapcioglu, B., Vatansever, S., Karan, M.A., Akkaya, V., Erk, O., 2005. The effect of air pollution and meteorological parameters in Istanbul on hospital admissions for acute coronary syndrome. Indoor Built Environ. 14, 157–164.

Jo, E.J., Lee, W.S., Jo, H.Y., Kim, C.H., Eom, J.S., Mok, J.H., Kim, M.H., Lee, K., Kim, K. U., Lee, M.K., Park, H.K., 2017. Effects of particulate matter on respiratory disease and the impact of meteorological factors in Busan, Korea. Respir. Med. 124, 79–87.

Jumaah, H.J., Ameen, M.H., Kalantar, B., Rizeei, H.M., Jumaah, S.J., 2019. Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia. Geomatics, Nat. Hazards Risk 10 (1), 2185–2199.

Kampa, M., Castanas, E., 2008. Human health effects of air pollution. Environ. Pollut. 151, 362–367.

Kara, M.B., Kaynak, B., 2017. Evaluation of ground-based SO_2 measurements in Turkey and examination of spatial and temporal variation of SO_2 pollution. In: 7th National Air Pollution Control Symposium.

Khaefi, M., Geravandi, S., Hassani, G., Yari, A.R., Soltani, F., Dobaradaran, S., Moogahi, S., Mohammadi, M.J., Mahboubi, M., Alavi, N., Farhadi, M., 2017. Association of particulate matter impact on prevalence of chronic obstructive pulmonary disease in Ahvaz, southwest Iran during 2009-2013. Aerosol Air Qual. Res. 17 (1), 230–237.

Khanum, F., Chaudhry, M.N., Kumar, P., 2017. Characterization of five-year observation data of fine particulate matter in the metropolitan area of Lahore. Air Quality, Atmosphere Health 10 (6), 725–736.

Ko, F.W.S., Tam, W., Wong, T.W., Chan, D.P.S., Tung, A.H., Lai, C.K.W., Hui, D.S.C., 2007. Temporal relationship between air pollutants and hospital admissions for chronic obstructive pulmonary disease in Hong Kong. Thorax 62, 780–785.

Le, T.H., Thanh Nguyen, T.N., Lasko, K., Ilavajhala, S., Vadrevu, K.P., Justice, C., 2014. Vegetation fires and air pollution in Vietnam. Environ. Pollut. 195, 267–275.

Lee, S., Lee, W., Kim, D., Kim, E., Myung, W., Kim, S.-Y., Kim, H., 2019. Short-term $PM_{2.5}$ exposure and emergency hospital admissions for mental disease. Environ. Res.

Li, L., Yang, J., Song, Y.F., Chen, P.Y., Ou, C.Q., 2016. The burden of COPD mortality due to ambient air pollution in Guangzhou, China. Sci. Rep. 6 (1).

Lu, P., Zhang, Y., Lin, J., Xia, G., Zhang, W., Knibbs, L.D., Morgan, G.G., Jalaludin, B., Marks, G., Abramson, M., Li, S., Guo, Y., 2019. Multi-city study on air pollution and hospital outpatient visits for asthma in China. Environ. Pollut. 113638.

Lv, D., Ying, C., Zhu, T., Li, T., Shen, F., Li, X., 2019. The pollution characteristics of PM_{10} and $PM_{2.5}$ during summer and winter in Beijing, Suning and Islamabad. Atmos. Pollut. Res. https://doi.org/10.1016/j.apr.2019.01.021.

Ma, J., Ding, Y., Gan, V.J.L., Lin, C., Wan, Z., 2019. Spatiotemporal prediction of $PM_{2.5}$ concentrations at different time granularities using IDW-BLSTM. IEEE Access 1–1.

Medina-Ramón, M., Zanobetti, A., Schwartz, J., 2006. The effect of ozone and PM_{10} on hospital admissions for pneumonia and chronic obstructive pulmonary disease: a national multicity study. Am. J. Epidemiol. 163, 579–588.

Meng, X., Wang, C., Cao, D., Wong, C.M., Kan, H., 2013. Short-term effect of ambient air pollution on COPD mortality in four Chinese cities. Atmos. Environ. 77, 149–154.

Mentese, S., Mirici, N.A., Elbir, T., Tuygun, G.T., Bakar, C., Otkun, M.T., Oymak, S., 2020. A comprehensive assessment of ambient air quality in Çanakkale city: emission inventory, air quality monitoring, source apportionment, and respiratory health indicators. Atmos. Pollut. Res. 11 (12), 2282–2296.

Mercan, Y., Babaoglu, U.T., Erturk, A., 2020. Short-term effect of particular matter and sulfur dioxide exposure on asthma and/or chronic obstructive pulmonary disease hospital admissions in Center of Anatolia. Environ. Monit. Assess. 192, 646.

Ministry of Environment and Urbanization, 2020. Canakkale province clean air action plan.

Nastos, P.T., Paliatsos, A.G., Anthracopoulos, M.B., Roma, E., Priftis, K.N., 2010. Outdoor particulate matter and childhood asthma admissions in Athens, Greece: a time-series study. Environ. Health 9, 45. https://doi.org/10.1186/1476-069X-9-45.

Nhung, N.T.T., Schindler, C., Dien, T.M., Probst-Hensch, N., Perez, L., Kunzli, N., 2018. Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: an eight-year time series study. Environ. Int. 110, 139–148.

Nhung, N.T.T., Schindler, C., Dien, T.M., Probst-Hensch, N., Kunzli, N., 2019. Association of ambient air pollution with lengths of hospital stay for Hanoi children with acute lower-respiratory infection. Environ. Pollut. 247, 752–762. https://doi:10.1016/j.envpol.2019.01.115, 2007–2016.

Ozcan, N.S., Cubukcu, K.M., 2015. Evaluation of air pollution effects on asthma disease: the case of Izmir. Soc. Behav. Sci. 202, 448–455.

Peacock, J.L., Anderson, H.R., Bremner, S.A., Marston, L., Seemungal, T.A., Strachan, D. P., Wedzicha, J.A., 2011. Thorax 66, 591–596.

Perez, L., Grize, L., Infanger, D., Kunzli, N., Sommer, H., Alt, G.M., Schindler, C., 2015. Associations of daily levels of PM_{10} and NO_2 with emergency hospital admissions and mortality in Switzerland: trends and missed prevention potential over the last decade. Environ. Res. 140, 554–561.

Pikhart, H., Bobak, M., Gorynski, P., Wojtyniak, B., Danova, J., Celko, M.A., Kriz, B., Briggs, D., Elliott, P., 2001. Outdoor sulphur dioxide and respiratory sysmptoms in Czech and Polish school children: a small-area study (SAVIAH). Int. Arch. Occup. Environ. Health 74, 574–578.

Polezer, G., Tadano, Y.S., Siqueira, H.V., Godoi, A.F.L., Yamamoto, C.I., de André, P.A., Pauliquevis, T., Andrade, M.F., Oliveira, A., Saldiva, P., Taylor, P., Godoi, R.H.M., 2018. Assessing the impact of $PM_{2.5}$ on respiratory disease using artificial neural networks. Environ. Pollut. 235, 394–403.

Pope, C.A., Hansen, M.L., Long, R.W., Nielsen, K.R., Eatough, N.L., Wilson, W.E., Eatough, D.J., 2004. Ambient particulate air pollution, heart rate variability, and blood markers of inflammation in a panel of elderly subjects. Environ. Health Perspect. 112, 339–345.

R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org/.

Sahin, U.A., 2020. The effects of COVID-19 measures on air pollutant concentrations at urban and traffic sites in Istanbul. Aerosol Air Qual. Res. 20 (9), 1874–1885.

Saki, H., Goudarzi, G., Jalali, S., Barzegar, G., Farhadi, M., Parseh, I., Geravandi, S., Salmanzadeh, S., Yousefi, F., Mohammadi, M.J., 2020. Study of Relationship between Nitrogen Dioxide and Chronic Obstructive Pulmonary Disease in Bushehr, Iran. Clinical Epidemiology and Global Health.

Santurtún, A., Rasilla, D.F., Riancho-Zarrabeitia, L., Zarrabeitia, M.T., 2017. Relationship between chronic obstructive pulmonary disease and air pollutants depending on the origin and trajectory of air masses in the north of Spain. Arch. Bronconeumol. 53 (11), 616–621.

Santus, P., Russo, A., Madonini, E., Allegra, L., Blasi, F., Centanni, S., Miadonna, A., Schiraldi, G., Amaducci, S., 2012. How air pollution influences clinical management of respiratory diseases. A case-crossover study in Milan. Respir. Res. 13, 95.

Saygin, M., Gonca, T., Ozturk, O., Has, M., Calıskan, S., Has, Z.G., Akkaya, A., 2017. To investigate the effects of air pollution (PM_{10} and SO_2) on the respiratory diseases asthma and chronic obstructive pulmonary disease. Turkish Thoracic J. 18, 33–39.

Schikowski, T., Sugiri, D., Ranft, U., Gehring, U., Heinrich, J., Wichmann, H.E., Kramer, T., 2005. Long-term air pollution exposure and living close to busy roads are associated with COPD in women. Respir. Res. 6, 152. https://doi.org/10.1186/1465-9921-6-152.

Stieb, D.M., Szyszkowicz1, M., Rowe, B.H., Leech, J.A., 2009. Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. Environ. Health 8, 25.

Sindosi, O.A., Markozannes, G., Rizos, E., Ntzani, E., 2019. Effects of economic crisis on air quality in Ioannina, Greece. J. Environ. Sci. Health A 1–14.

Tahery, N., Geravandi, S., Goudarzi, G., Shahriyari, H.A., Jalali, S., Mohammadi, M.J., 2021. Estimation of PM_{10} pollutant and its effect on total mortality (TM), hospitalizations due to cardiovascular diseases (HACD), and respiratory disease (HARD) outcome. Environ. Sci. Pollut. Control Ser. 28 (17), 22123–22130.

Tao, Y., Mi, S., Zhou, S., Wang, S., Xie, X., 2014. Air pollution and hospital admissions for respiratory diseases in Lanzhou, China. Environ. Pollut. 185, 196–201.

Tecer, L.H., Alagha, O., Karaca, F., Tuncel, G., Eldes, N., 2008. Particulate matter ($PM_{2.5}$, $PM_{10\text{-}2.5}$, and PM_{10}) and children's hospital admissions for asthma and respiratory diseases: a bidirectional case-crossover study. J. Toxicol. Environ. Health 71, 512–520.

Tellaetxe, U., Carslaw, D.C., 2014. Conditional bivariate probability function for source identification. Environ. Model. Software 59, 1–9, 0.

Tomášková, H., Tomášek, I., Šlachtová, H., Polaufová, P., Šplíchalová, A., Michalík, J., Feltl, D., Lux, J., Marsová, M., 2016. PM_{10} air pollution and acute hospital admissions for cardiovascular and respiratory causes in OSTRAVA. Cent. Eur. J. Publ. Health 24, 33–39.

Tomczak, A., Miller, A.B., Weichenthal, S.A., To, T., Wall, C., Donkelaar, A.V., Martin, R. V., Crouse, D.L., Villeneuve, P.J., 2016. Long-term exposure to fine particulate matter air pollution and the risk of lung cancer among participants of the Canadian National Breast Screening Study. Int. J. Cancer 139, 1958–1966.

Wang, Y., Liu, X., Chen, G., Tu, R., Abdulai, T., Qiao, D., Liu, X., Dong, X., Luo, Z., Wang, Y., Li, R., Huo, W., Yu, S., Guo, Y., Li, S., Wang, C, 2020. Association of long-term exposure to ambient air pollutants with prolonged sleep latency: The Henan Rural Cohort Study. Environ. Res. 191, 110116.

Wilson, A.M., Wake, C.P., Kelly, T., Salloway, J.C., 2005. Air pollution, weather and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environ. Res. 97, 312–321.

World Health Organization (WHO), 2020. https://www.who.int/news-room/fact-sheets/detail/asthma. (Accessed August 2020).

Xie, X., Wang, Y., Yang, Y., Xu, J., Zhang, Y., Tang, W., Guo, T., Wang, Q., Shen, H., Zhang, Y., Yan, D., Peng, Z., Chen, Y., He, Y., Ma, X., 2018. Long-term exposure to fine particulate matter and tachycardia and heart rate: results from 10 million reproductive-age adults in China. Environ. Pollut. 242, 1371–1378.

Zeng, Y.-R., Chang, Y.S., Fang, Y.H., 2019. Data visualization for air quality analysis on bigdata platform. In: International Conference on System Science and Engineering (ICSSE). https://doi.org/10.1109/icsse.2019.8823437.

Zhang, Y., Xiang, Q., Yu, C., Yang, Z., 2020. Asthma Mortality Is Triggered by Short-Term Exposures to Ambient Air Pollutants: Evidence from a Chinese Urban Population. Atmospheric Environment, p. 117271.

Zhang, J., Ren, D., Cao, X., Wang, T., Geng, X., Li, X., Tang, J., Leng, S., Wang, H., Zheng, Y., 2021. Ambient air pollutants and hospital visits for pneumonia: a case-crossover study in Qingdao, China. BMC Publ. Health 21, 66. https://doi.org/10.1186/s12889-020-10065-0.

Zhao, S., Liu, S., Hou, X., Beazley, R., Sun, Y., Dong, S., 2019. Evidence of provincial variability in air pollutants-asthma relations in China. J.Clean. Prod. 118553.

Zheng, P., Wang, J., Zhang, Z., Shen, P., Chai, P., Li, D., Chen, K., 2017. Air pollution and hospital visits for acute upper and lower respiratory infections among children in Ningbo, China: a time-series analysis. Environ. Sci. Pollut. Control Ser. 24 (23), 18860–18869.